

LIGHTING FACTORS AFFECTING THE VISIBILITY OF A MOVING DISPLAY

Richard D. Gilson and Robert H. Elliott

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Compensatory tracking
Display oscillation
Display illumination

Compensatory tracking performance was shown to be substantially degraded by oscillation of the visual display at both 1.0 Hz and 2.0 Hz. The severity of this decrement was significantly altered by changes in both the color and the intensity of the display illumination. Performance was significantly better with red light illuminating the display at 0.05 mL than with blue light at the equivalent luminance. This improvement in performance was similar in magnitude to that found for an increase in broad-band illumination of the display where luminance was increased from one-half log unit below to one-half log unit above 0.05 mL. Visual mechanisms that may have been responsible for these findings are suggested and practical considerations of instrument lighting are discussed.

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SUMMARY PAGE

THE PROBLEM

An increase in flight-instrument illumination was previously shown to be a significant factor in counteracting deterioration in compensatory tracking performance due to vestibular-evoked eye movements. Further investigation was undertaken to reveal if changes in the color of the illuminating light would also be effective in altering performance. In this experiment, relative motion between the eyes and the display was introduced by oscillation of the visual display.

FINDINGS

Tracking performance was substantially degraded by display oscillation at both 1.0 Hz and 2.0 Hz. The severity of this decrement was significantly altered by changes in both color and the intensity of the display illumination. Performance was significantly better with red light illuminating the display at 0.05 m^L than with blue light at the equivalent luminance. This improvement in performance was similar in magnitude to that found for an increase in broad-band illumination of the display where luminance was increased from one-half log unit below to one-half log unit above 0.05 m^L.

Visual mechanisms that may have been responsible for these findings are suggested and practical considerations of instrument lighting are discussed.

ACKNOWLEDGMENT

The authors gratefully acknowledge Mr. David J. Gripka's assistance in analyzing these data.

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The findings in this report are not to be construed as official Departments of the Army and Navy positions, unless so designated by other authorized documents.

INTRODUCTION

A recent study by Gilson, Benson, and Guedry (2) investigated the effects of vestibular stimulation on the performance of a compensatory tracking task. During performance of the task, periodic stimulation of the semicircular canals by angular acceleration introduced nystagmic eye movements. As the visual display, an aircraft instrument, was fixed relative to the subject, such eye movements resulted in image movement across the retina which in turn caused blurring of vision and hence degraded tracking performance. Under these conditions, a systematic increase in the luminance of the tracking display from 0.01 to 10.0 ft-L markedly improved performance without producing a significant change in nystagmus. The same changes in luminance did not significantly affect performance in the absence of vestibular stimulation. Thus, the alteration in tracking performance with display luminance during vestibular stimulation appeared to depend upon a visual process in which an increase in luminance counteracted the blurring effects of image movement on the retina.

A similar phenomenon has been observed previously. Several investigators (6,8-10) have reported that visual acuity is impaired by relative motion between the eyes and a test pattern, and that increasing illumination counteracted this impairment. Miller (9) and Mackworth and Kaplan (8) further showed, as did Gilson et al. (2), that the effect of illumination was magnified as the speed of the relative motion was increased.

Ludvigh (6) attributed this phenomenon to a reduction in the intensity contrast as a result of continual movement of the image on the retina. Accordingly, the effect of increased illumination was simply to reintensify contrast.

It is curious, however, that the most pronounced effects appeared to occur at low illumination levels. Gilson et al. (2) found that equal log-unit changes in display luminance differentially affected visual tracking performance, with the greatest effect occurring between 0.01 and 0.10 ft-L. It is quite possible that at these low levels of illumination, scotopic visual processes were largely involved, whereas at higher levels photopic processes dominated. The underlying causes, then, might have not been intensity contrast alone, but also the relative degree to which scotopic or photopic visual processes were involved.

The present investigation was undertaken to examine this possibility by comparing subjects' visual performance when a moving display was illuminated by different colored lights. The lights were equated for luminance, but chosen to enhance photopic vision in one condition and scotopic vision in the other.

PROCEDURE

SUBJECTS

Fifteen naval and marine officers between the ages of 21 and 25 years participated in the experiment. All were student aviators who had passed standard Navy flight

physical requirements that included uncorrected 20/20 vision without color defects.

APPARATUS AND METHOD

A compensatory visual tracking task provided both a direct practical measure of performance and an indirect measure of visual acuity. The tracking apparatus has been described in detail elsewhere (2). Briefly, a complex "forcing function" input deflected the vertical needle of an aircraft localizer/glide slope indicator while the subject attempted to maintain the needle in a null position by manipulation of a control stick. Deviations of the needle from this position were considered errors, and a voltage proportional to these deviations was electronically integrated over consecutive 1-sec intervals throughout a trial.

In the present experiment a simple sinusoidal forcing function with a 14-sec period was used to deflect the vertical needle. Errors were also integrated for 42 sec, or three complete cycles of the forcing function, in order to obtain one number for each experimental condition.

Relative motion between the eyes and the display was introduced by moving a mirror view of the display. The subject binocularly viewed the display reflection in a mirror which was oscillated about its vertical axis. One end of the mirror was connected by a jointed arm to an off-center position on a remote shaft. This shaft was rotated by a two-speed, constant speed motor causing the mirror to move in approximately a sinusoidal manner. With the subject's eyes and the display equidistant from the mirror (40 cm), the visual angular displacement of the image was the same as the angular displacement of the mirror. The result was the effective movement of the display to the left and right of the subject's view according to the same sinusoidal function as the mirror.

The visual angle between the two extreme display positions was 10 deg. The frequency of display oscillation was 1 Hz with the motor at low speed and 2 Hz with the motor at high speed. These values of angular displacement and frequency are in the range of those obtained for nyctagmic responses in the previous study (2).

The subject sat in front of the mirror with his head supported by a chin rest. The control stick was attached within convenient reach to the bottom of the table and was activated from side to side to correspond with needle movements.

The display was illuminated by a Kodak carousel 750 automatic slide projector. Light was projected through a tube to illuminate the display which was shielded from direct viewing.

Experimental condition: of both wavelength and luminance were controlled by Kodak Wratten gelatin filters mounted in glass slides and inserted into the projector. Two slides contained cutoff filters #47B (blue) and #25A (red) that passed energy below

approximately $500\text{ m}\mu$ and above approximately $580\text{ m}\mu$, respectively. The blue filter should, according to accepted scotopic and photopic curves (1), stimulate scotopically with greater efficiency at low illumination than photopically. Conversely, the red filter should stimulate photopically with greater efficiency than scotopically.

The red, the blue, and a third neutral density filter were equated for luminance by superimposing additional neutral density filters into the slides until the luminance on the display was 0.05 mL. Two other slides also containing neutral density filters were selected to give values of 0.5 log unit above and below 0.05 mL (0.158 and 0.016 mL), respectively.

The luminance of the display was measured with the aid of a card sprayed with the same white paint as the needles of the display. This card was placed in the light, just in front of the display, and measurements were made with a MacBeth illuminometer from the subject's viewing position via the mirror. Three observers experienced with the use of the (MacBeth) illuminometer for heterochromatic brightness measurements made numerous readings on three separate occasions for each of the five filter combinations. The variability of these readings ranged over, but did not exceed, ± 0.3 log unit.

It is stressed that the foregoing procedure entailed a subjective brightness match for the colors. No attempt was made to equate for the energy distribution of the transmitted light.

A total of fifteen experimental conditions were examined. Each of the five filters was coupled with three conditions of display movement: no movement, oscillation at 1.0 Hz, and oscillation at 2.0 Hz. The order of presentation was randomized within the restrictions imposed by a Latin square design to counterbalance order effects.

Each subject initially underwent a 7-min period of dark adaptation. He was told that the task was to keep the needle of the display centered for as much of the time as possible, even though the needle might become blurred. During the next 3 min the subject practiced tracking with the 0.05 mL neutral density filter and with the display oscillating at 1.0 Hz. At the end of this practice period the filter and display frequency were immediately changed to the first condition of the selected sequence. Approximately 15 sec of tracking during each condition was allowed for tracking performance to stabilize before the 42-sec scoring interval began.

RESULTS AND DISCUSSION

The results are shown in Figure 1. It is evident that as frequency of display oscillation was increased, so was tracking error, regardless of the illuminating condition. This finding is in agreement with other studies (7,9) where impairment of acuity was positively correlated with increased velocity of the test object.

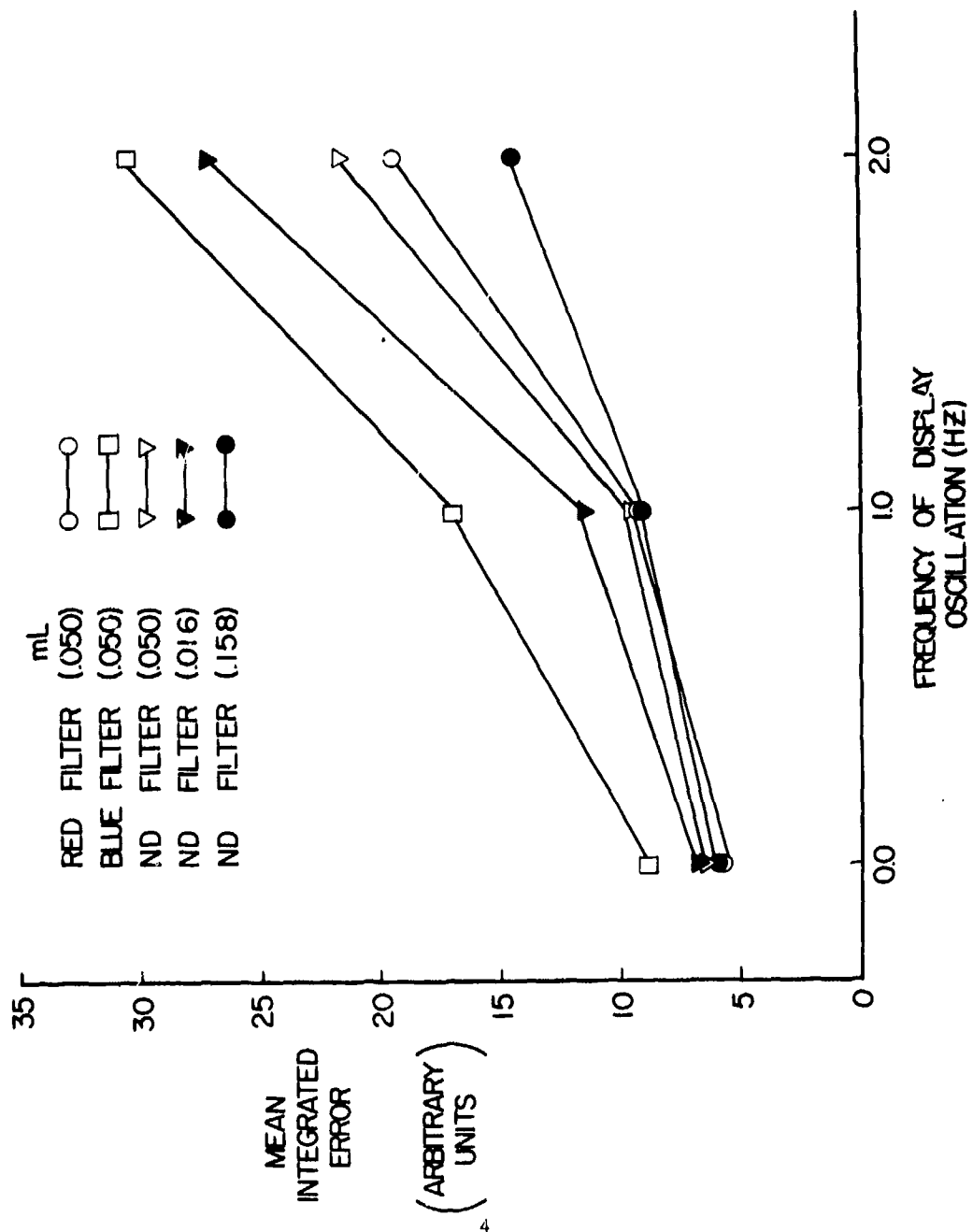


Figure 1

Effect of display illumination on compensatory tracking performance during sinusoidal oscillation of the display. Each point is the mean integrated error score over 42 sec of tracking for 15 subjects. Error scores are plotted for the condition of illumination and frequency of display oscillation. ND = Neutral Density.

The type of illumination appears to determine the rate of increase of tracking error with display frequency. As indicated previously, other studies (2,8,9) have shown that increased illumination reduced the acuity loss or decrement in tracking performance produced by either display or eye movements and that this effect increased with the speed of the motion. This is apparent in the present results even with only a 1-log unit over-all change in luminance. The curves depicting the results for the three neutral density filters diverge, as frequency increases, to a degree where the performance at the brightest illumination is significantly better ($P < .01$) than at the lowest illumination at 2.0 Hz.

In a similar manner, the curves for tracking performance with the blue and red filters diverge and differ significantly ($P < .01$) at both 1.0 Hz and 2.0 Hz. Despite equation for luminance, the differences in these curves are similar to those obtained for the log-unit change in luminance between the dim and bright neutral density filters.

Thus, this effect is not merely the result of luminance changes alone but of some other factor associated with changes in both luminance and wavelength. The low luminance levels and specific wavelengths for which this effect is most apparent border on the transition between scotopic and photopic stimulation (1). This lends support to the hypothesis that differences between scotopic and photopic visual processes may be involved. The similarity in performance for the red and equally bright neutral density filter may well be the result of the light passed by the neutral filter stimulating both visual processes, with the more efficient photopic process prevailing. As such, the similarity between the two curves may attest to the reliability of the data.

Graham (4) has speculated on how movement of an image across the retina may reduce border contrast. His arguments are based in part on the reduced stimulation of a given retinal element according to the Bunsen-Roscoe law and in part on inhibition and facilitation of adjacent retinal elements as the image moves across them. If such processes do in fact govern border contrast during image movement, then the present results indicate that one or both of these processes are different for the rods than for the cones.

Numerous techniques have been used previously to achieve retinal image motion: by moving a test object in either a circular (6), horizontal (7), or vertical (9,10) path; by rotating the observer at constant velocity while he viewed a reflection of a stationary test object from a mirror rotating with him (9); by requiring the observer to fixate on a moving fixation target during which time a stationary test object was momentarily presented in the viewing field (8); and by requiring the observer to view a display fixed relative to himself, while undergoing vestibular stimulation sufficient to evoke nystagmic eye movements (2,3).

Except under the latter two conditions where the display remains fixed relative to the subject and all image movements on the retina are a direct result of eye movements, both the motion of the display and attempts by the eye to follow the display influenced image movement. Thus, the difference between display motion and inadequate or inappropriate pursuit eye movements results in image movement across the retina.

Oculomotor pursuit of targets moving sinusoidally has been studied by a number of investigators, and a summary of results from these studies has been compiled by Huddleston (5). Interpolation from these pooled data for the conditions employed in the present study indicated that pursuit eye movements were sinusoidal in form for both display frequencies of 1.0 Hz and 2.0 Hz, yet the eyes followed to only 78 per cent and 33 per cent, respectively, of the display's full excursion and at a phase lag of 3 and 35 deg, respectively. Calculation from these figures of the mean absolute velocity of the image movement on the retina (mean retinal image speed) yielded values of 4.6 deg/sec and 30.0 deg/sec for display oscillation frequencies of 1.0 Hz and 2.0 Hz, respectively.*

When the present results are replotted according to mean retinal image speed, as in Figure 2, this simply alters the shape of the curves. However, this presentation of the data affords a more veridical independent variable (i.e., image speed on the retina). The shape of these curves is now similar to that obtained by Mackworth and Kaplan (8) who, by varying only eye velocity, were presumably measuring retinal image speed more directly.

Practically, the present results may serve as a warning against the use of certain blue lights or filters in situations where dim illumination and relative movement between the eyes and a display may occur; for example, displays in aircraft where the operator may encounter both instrument vibration and vestibular stimulation sufficient to evoke nystagmus. Under these conditions, visibility and performance may be substantially less affected with broad band or red illumination. The use of instruments marked with fluorescent paint may also avoid this problem since the paint emits visible radiation over a broad spectrum regardless of the color of the illuminating light. These results further emphasize those of others cited previously (2,6,8-10) that even a small change in luminance at low levels will strongly affect visual performance when there is relative motion between the eyes and a display. In questionable situations, either high luminance levels or long visual wavelengths at lower luminance levels will serve best to combat poor vision resulting from relative motion between the eyes and a display, apparently irrespective of the cause of the relative motion.

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* A pilot experiment for the present study utilizing electro-oculographic recordings from one subject failed to reveal any differences in oculomotor pursuit for any of the lighting conditions at display frequencies of either 1.0 Hz or 2.0 Hz, yet clearly showed the sinusoidal eye movements.

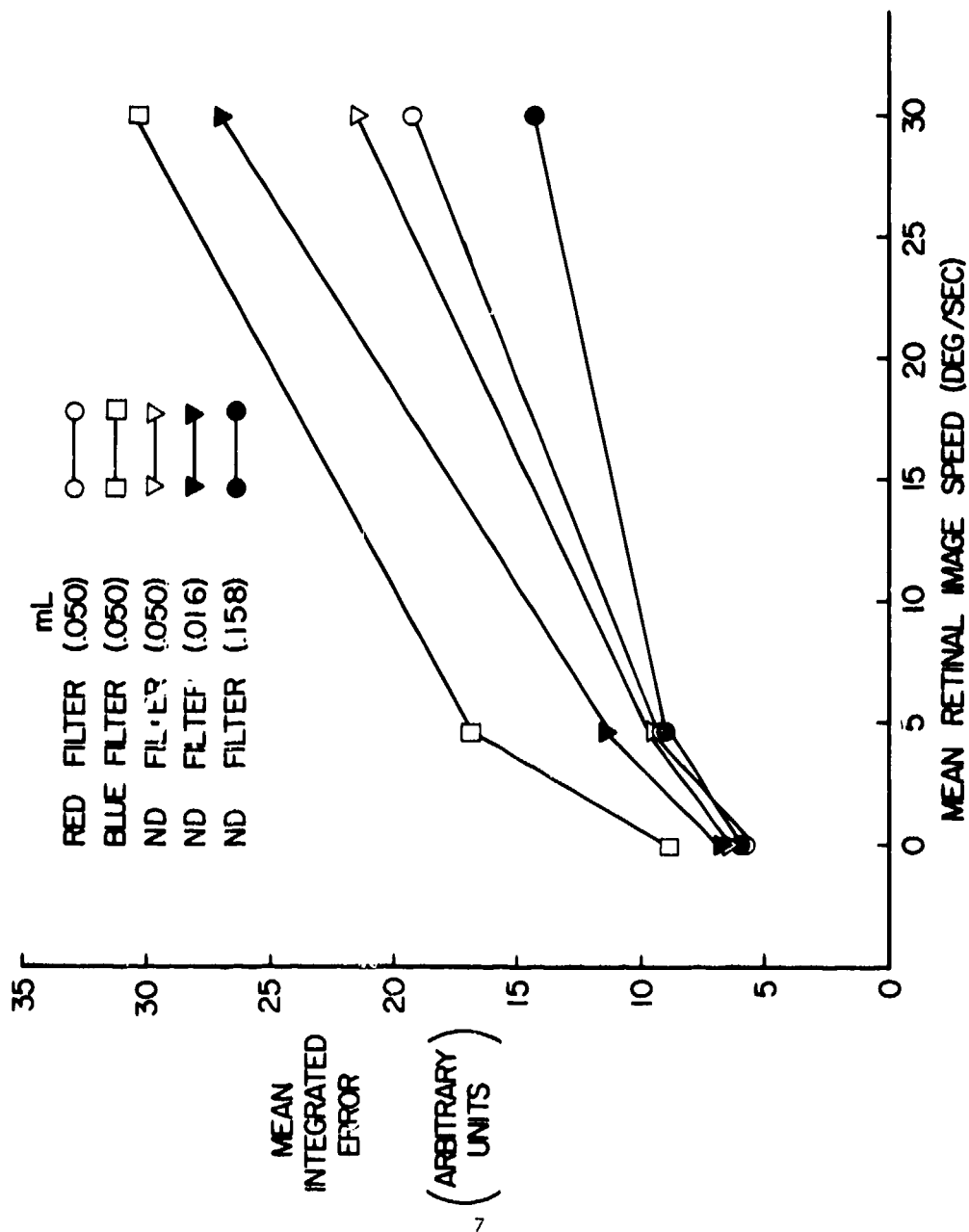


Figure 2

The same data as shown in Figure 1 except plotted for the average absolute velocity of the display image passing over the retina of the eye. These values were computed from the differential velocity of the eye and the display. Eye velocities were interpolated from Huddleston (5).

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